XPS/UPS and EFM

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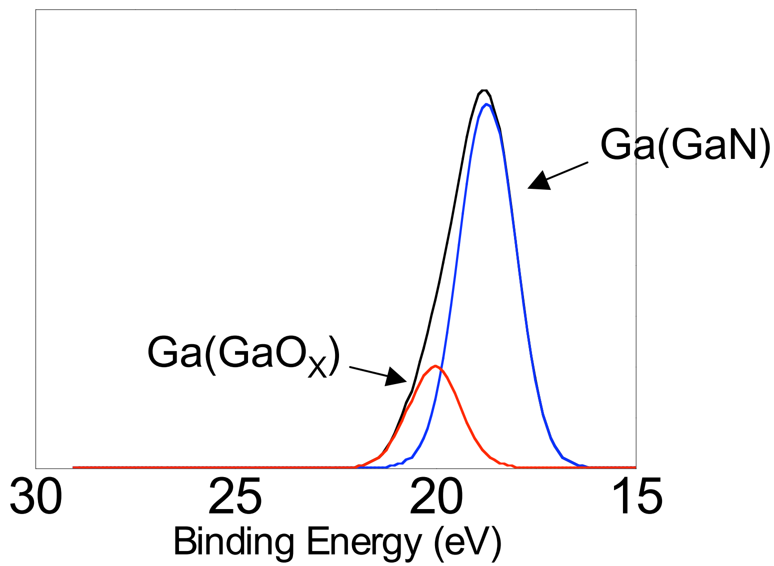
XPS/ESCA

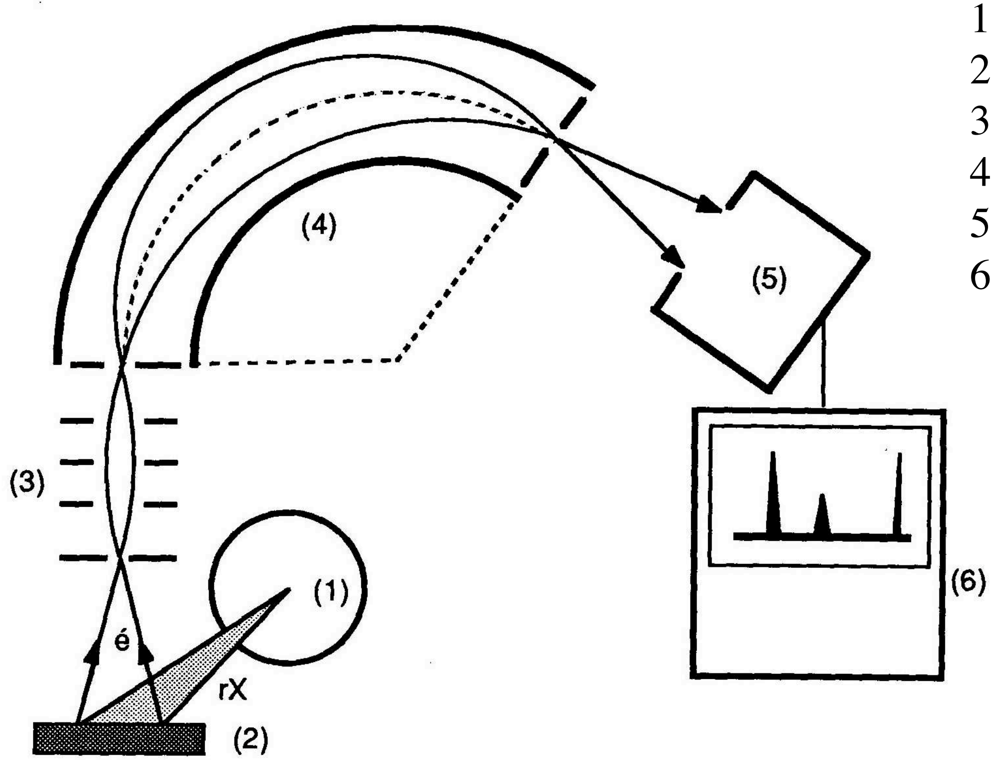
X-ray photoelectron spectroscopy (XPS) also called **Electron Spectroscopy for Chemical Analysis** (ESCA) is a chemical surface analysis method. XPS measures the chemical composition of the outermost 100 Å of a sample. Measurements can be made at greater depths by ion sputter etching to remove surface layers. All elements (except for H and He) can be detected at concentrations above 1.0 atom %. In addition, chemical bonding information can be determined from detailed analysis.



A Ga 3d peak with 2 curves fitted. Can determine relative concentration of Ga-O and Ga-N

XPS/UPS

XPS/ESCA Perkin-Elmer PHI 5100 ESCA System - MAIC



1. X-ray source – Mg or Al anode
2. Sample
3. Lens and aperture
4. Hemisphere energy analyzer
5. Position Sensitive Detector
6. Data Collection - Computer

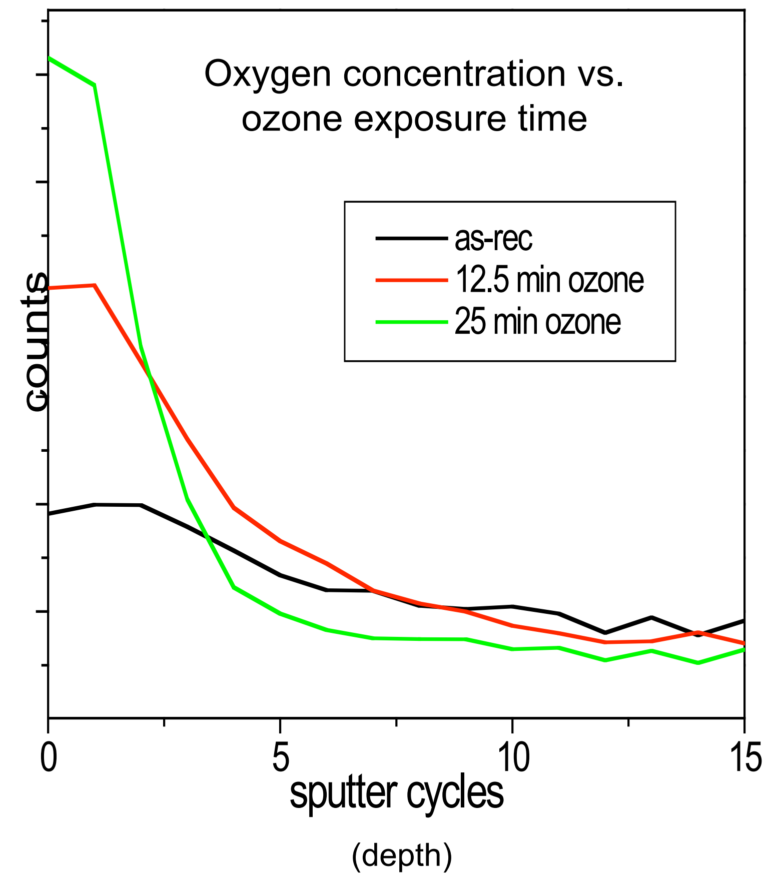
Past XPS use on HEMT passivation optimization

Optimize the ex-situ cleaning recipe

Used XPS to determine the surface composition/contamination and nature of the chemical bonding.

Oxygen surface conc. increases with ozone exposure time, however, oxygen depth does not. Surface converted to an oxynitride. (sample temperature~50°C)

Surface carbon concentration reduced 50% by conversion to CO and CO_2.

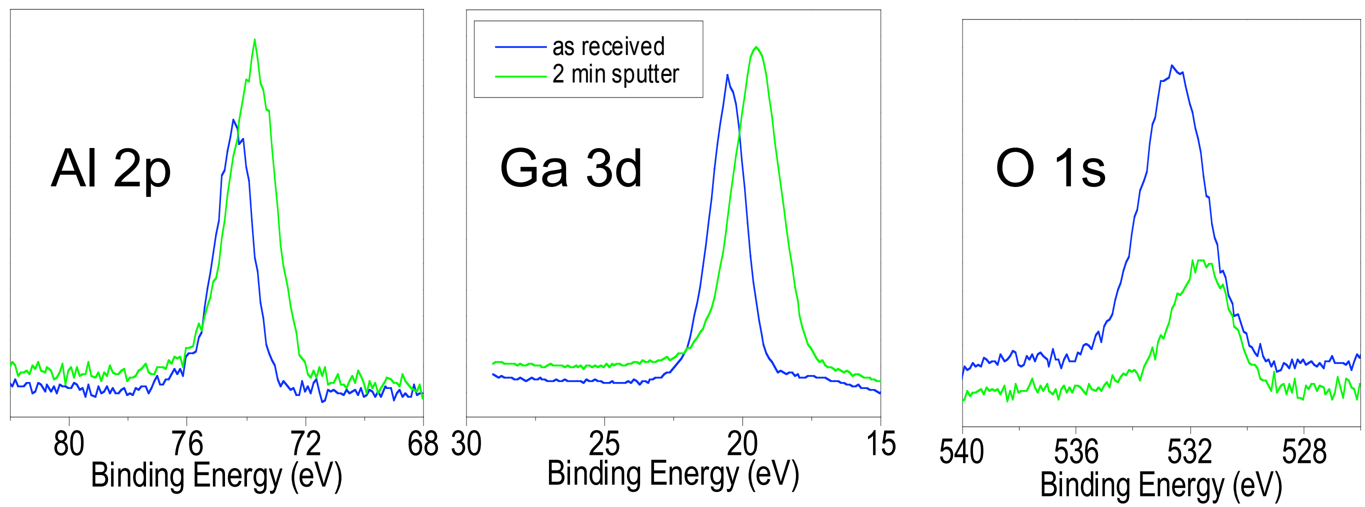


Past XPS use on HEMT passivation optimization

Oxynitride on AlGaN(23%) capped HEMT

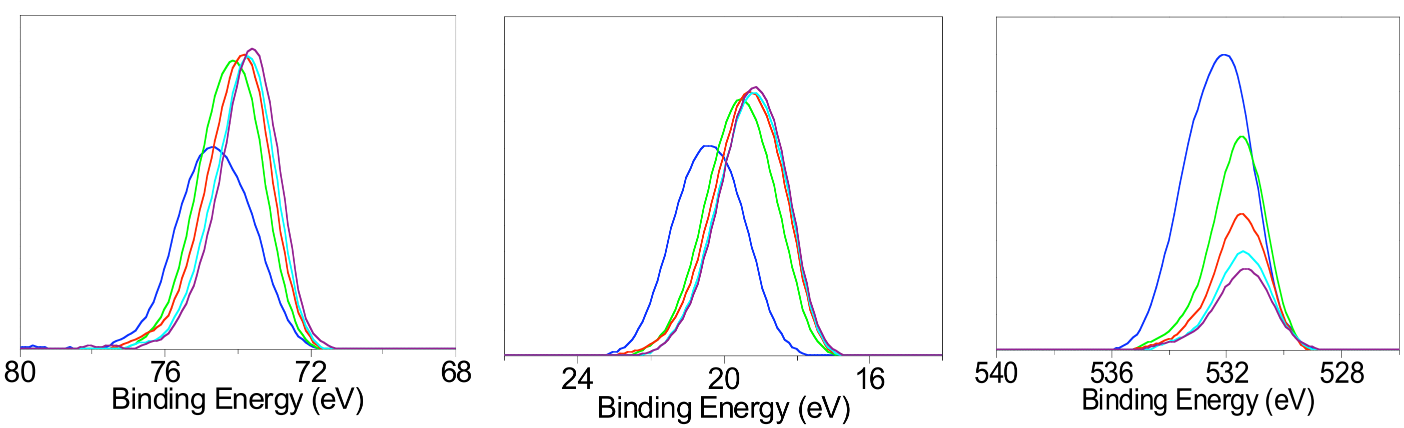
Native Oxide
(0.7eV surface charge)

- as-rec
- 1st sputter



UV-ozone Oxide
(0.6eV surface charge)

- as-rec
- 1st sputter
- 2nd sputter
- 3rd sputter
- 4th sputter

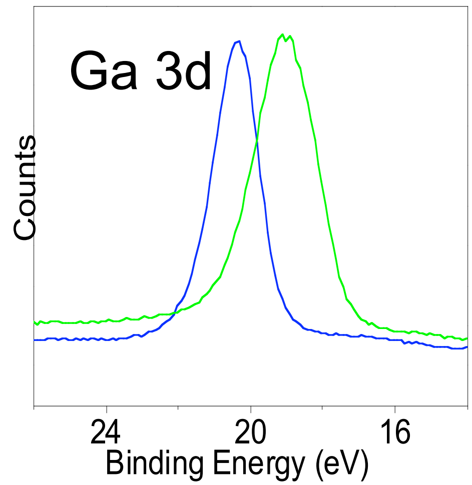


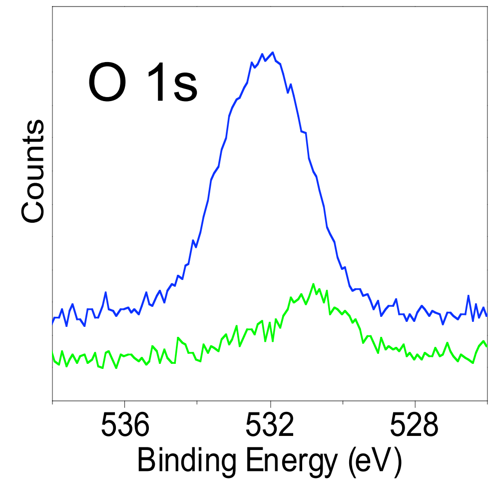
Past XPS use on HEMT passivation optimization

Oxynitride on GaN capped HEMT

Native Oxide
(0.6eV surface charge)

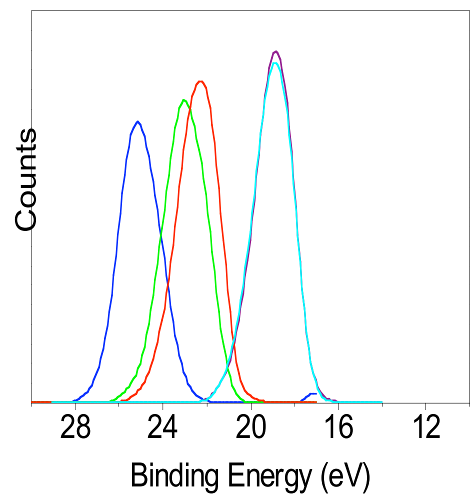
- as-rec
- 1st sputter

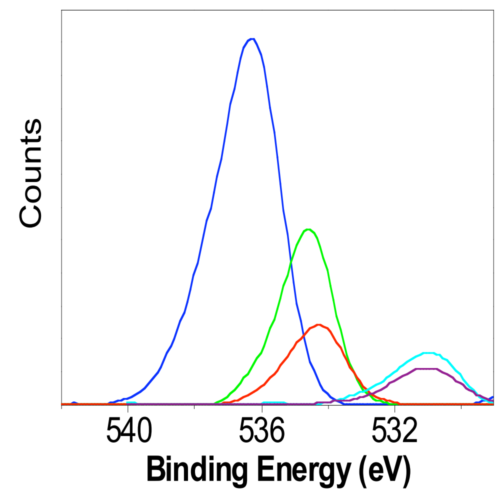




UV-ozone Oxide
(4.8eV surface charge)

- as-rec
- 1st sputter
- 2nd sputter
- 3rd sputter
- 4th sputter

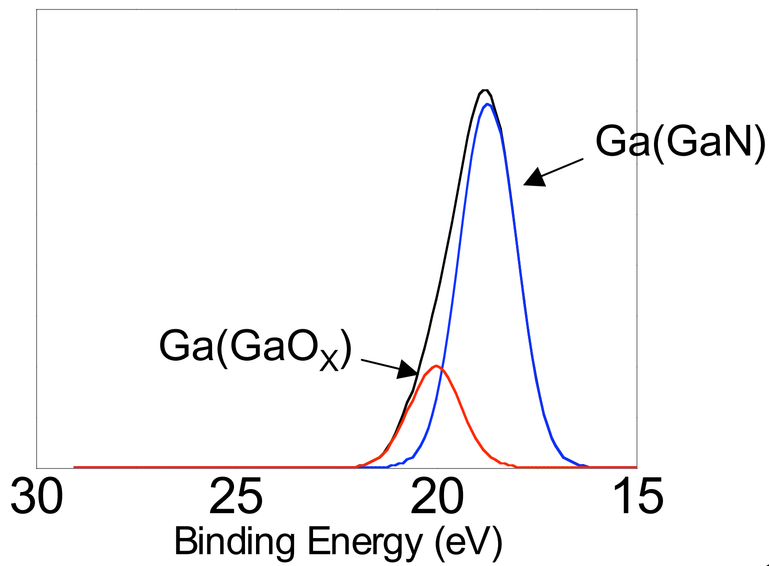




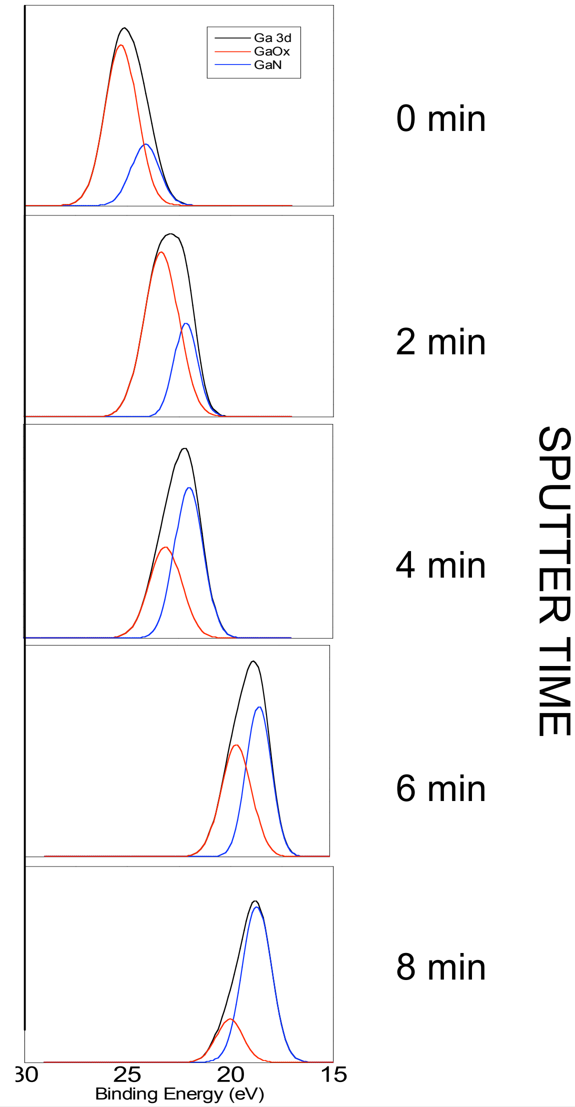
Past XPS use on HEMT passivation optimization

Ga 3d from GaN capped HEMT

As-Received GaN Surface



Notice the decrease in the GaO_X portion (corresponding with sputter time) and the shift in the Ga 3d signal as surface charge is reduced.

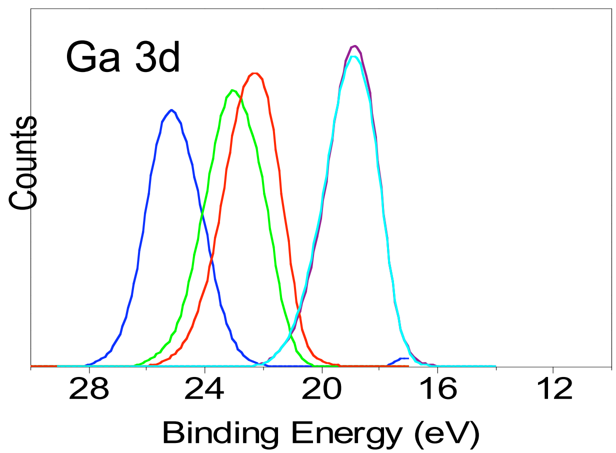


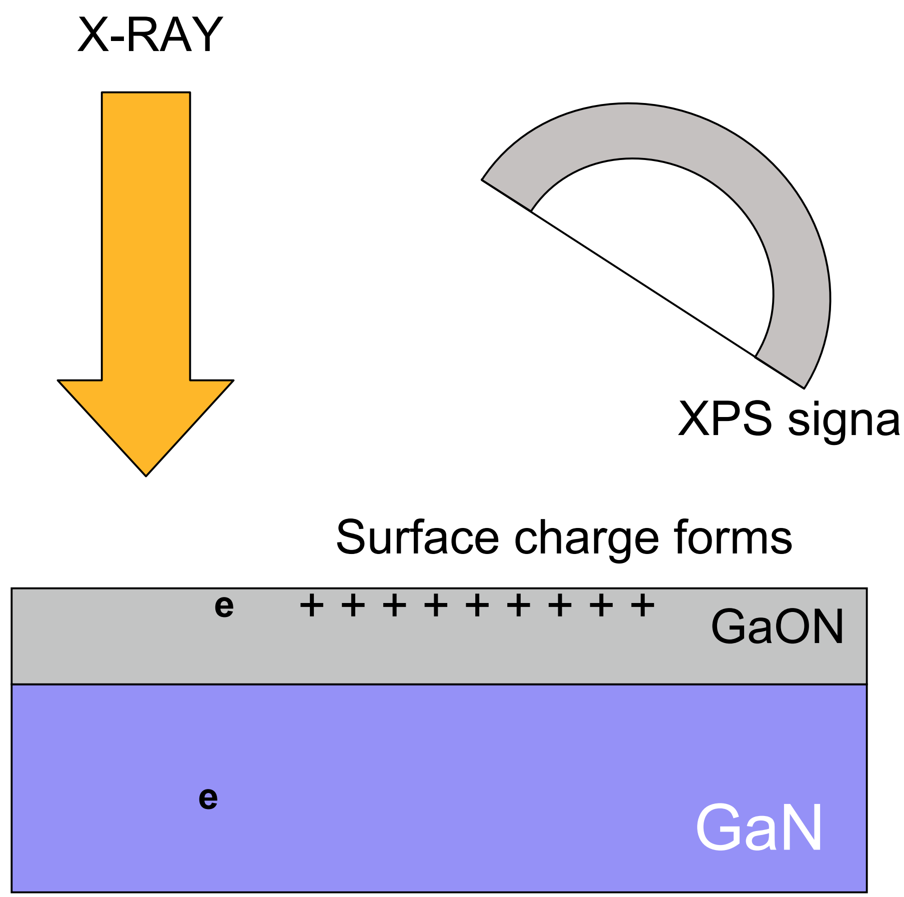
Past XPS use on HEMT passivation optimization

As x-rays enter the material, photo-electrons are generated from different depths.

Thick (2nm) ozone GaON is **not** conductive; electrons leaving the surface are **not** replenished from the bulk.

Large surface charge (4.8eV) **is** indicated from XPS spectra shift.





Past XPS use on HEMT passivation optimization

Current Collapse Measurements

HEMT structure	As-received	UV-Ozone treatment	Sc_2O_3 passivation
AlGaN cap 20-23%	50% of DC	35% of DC	80% of DC
GaN cap 3nm	40% of DC	40% of DC	95% of DC

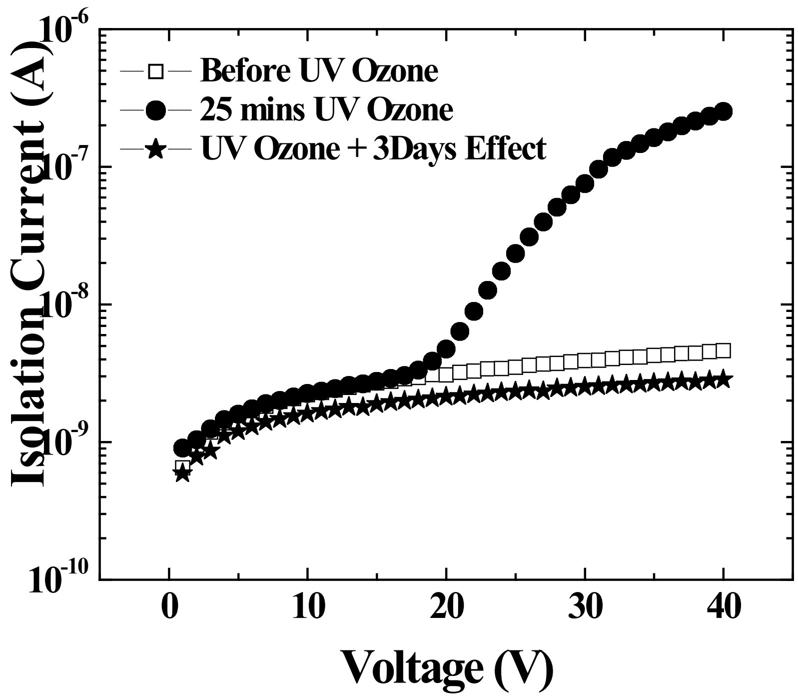
GaN capped HEMTs show better passivation that AlGaN capped HEMTs

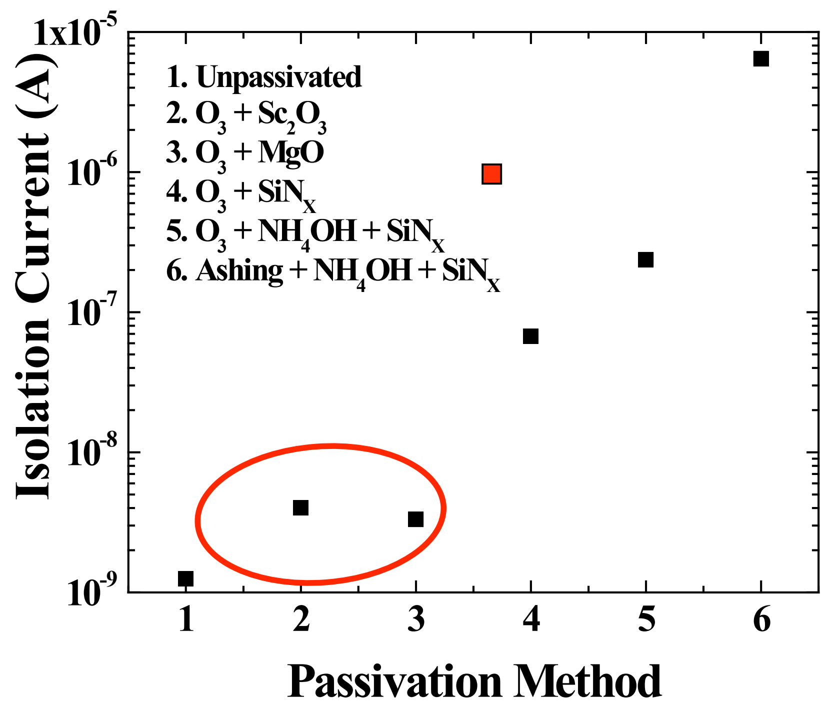
Increase in Al% = increase in surface reactivity = less passivation

Large scale features to aid in optimization

Effects on Isolation Current

mesa to mesa leakage measurements





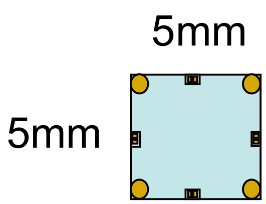
Must have isolation for realization of HEMT circuits.

Large scale features to aid in optimization

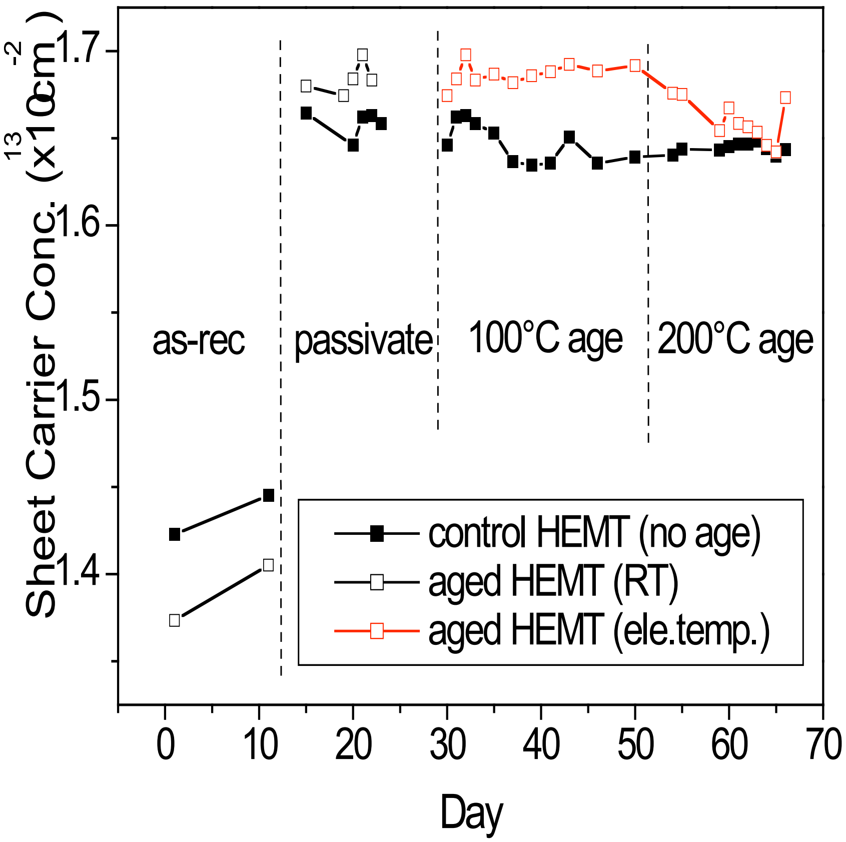
Passivation Reliability

Hall effect samples (5mm x 5mm) are processed to determine the passivation effect of the dielectric films. Samples are aged at elevated temperatures to determine effectiveness.

Hall Effect sample



Hall samples are large enough for further analysis (AFM, AES, XPS) for post aging studies.



Hall sample w/ 10nm MgO passivation, a 15% increases in sheet carrier density post passivation

Small spot XPS/UPS

Custom XPS/UPS on Nitride MBE system allows for sample transfer without exposure to atmosphere, 3” wafer capable.
Intermediate chamber available for additional processing or testing.

System based on a PHI 5400 XPS - Area resolution is $<500\mu m$, $2500 mm^2$ viewing area.

Aging of samples by both thermal stress (800°C sample heater) and bias stress (electrical feedthru to sample). Surface chemical desorption experiments and real-time diffusion data possible with sample heater.

Ultraviolet He arc discharge source installed for UPS

What UPS adds to the package

Mainly used for studies of the valence electron density of states. The VUV (10-200nm) discharge covers a useful range from 10 to 50 eV photon energy. The line width of excitation is generally a few meV, excellent for resolving molecular vibrational structures.

UV excited photoelectron spectra could be used for a comparison with band structure calculations and (in comparison with XPS) providing some additional fingerprint information in surface chemical analysis.
(ex. Determine Al_2O_3, $AlPO_4$, $Al_4(P_4O_{12})_3$ on a sample)

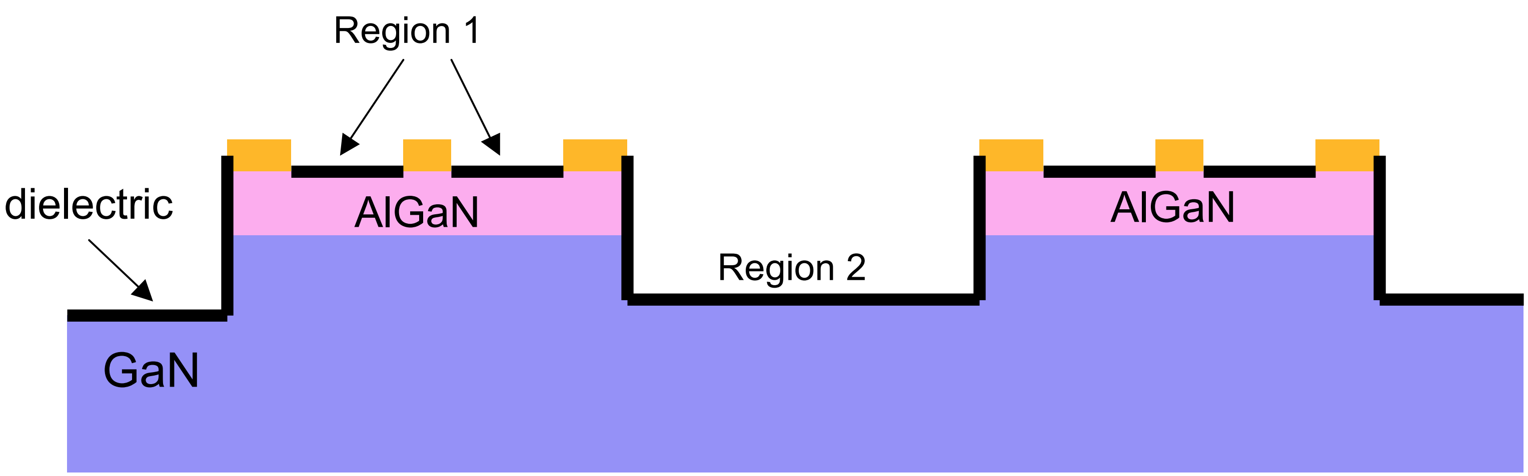
Provides a high resolution valance band spectra compared to XPS for determining valance band on surfaces.

Reliability of dielectrics

Reliability (aging) of the dielectric can be determined through both thermal stress and bias stress to determine method of failure. (large area features)

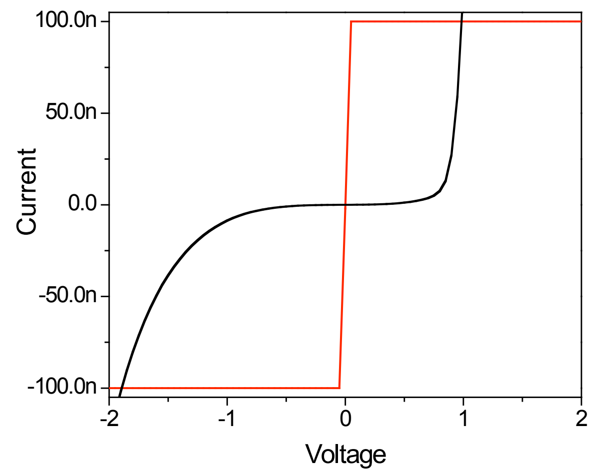
The two regions for dielectric coverage have significantly different surface chemistries and structure.

Identify key interface species/reactions that lead to stable passivation, isolation or field plates dielectric.



Metal contact failure mechanism

Ni/Au gate on HEMT after thermal failure

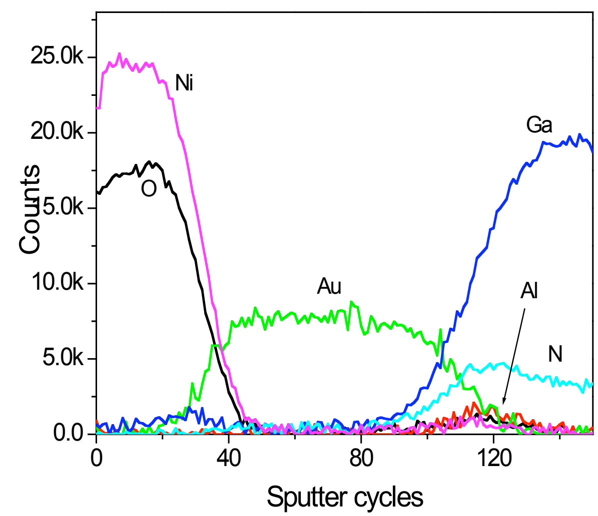


Using AES (area = micron to submicron) one can easily determine certain metal contact failure mechanisms.

Example: Ni/Au gate contact

The Ni diffuses to the surface, leaving Au in contact with the AlGaN.

Fairly straight forward.



Metal contact failure mechanism

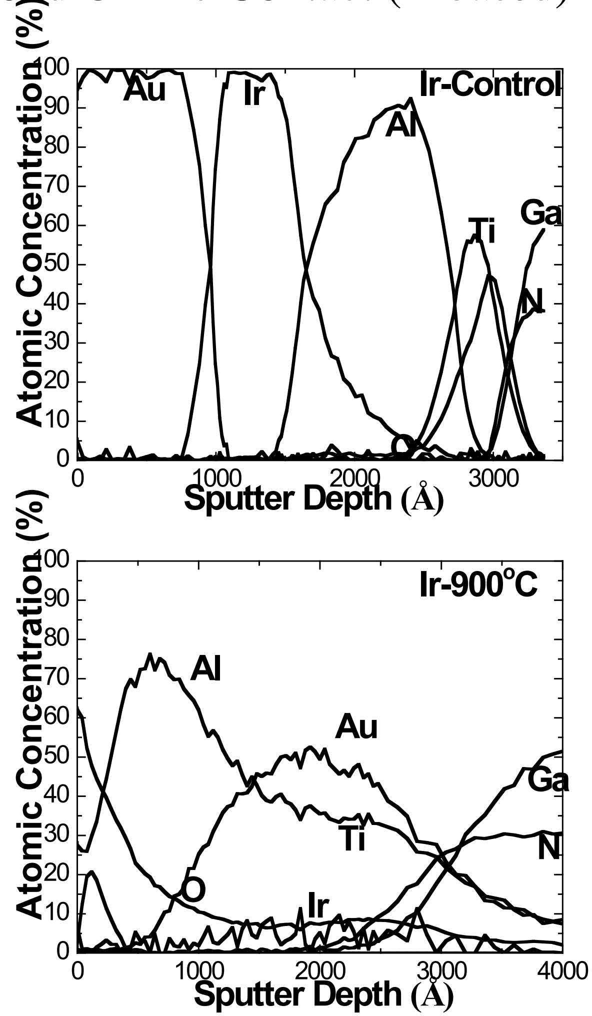
Failure of Ohmic contacts not as easily understood using AES.

Using AES one cannot determine the bonding state of the element, only the amount and depth position.

Example: A low resistivity ohmic contact is a blending of the different metals. Cannot determine if TiN interface formed.

Must use XPS.

Good Ohmic Contact (Ir based)

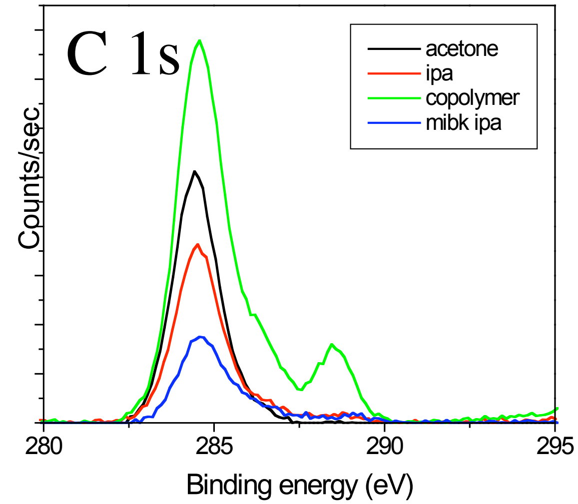


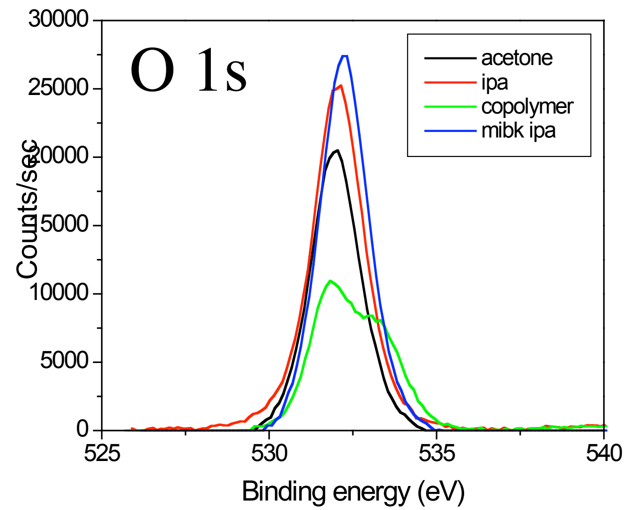
Identification of contamination

Use of XPS can identify different sources of carbon contamination that are left behind from device processing.

Characterization enhanced with UPS

AES can only determine that C and O are present, but not the species or source.





XPS/UPS

Projected Milestones

Year 1- Characterize operational and failed devices in the mesa isolation region. Determine changes in surface chemistry and work function. Correlate chemical/electrical changes.

Year 2- Design test structures to be placed in the die cut lines. Apply test structures to the cut lines and investigate variations in surface chemistry from post field stressing.

Year 3- Design in-situ bias stressing fixture for XPS-UPS. Characterize cut line test structures under bias stress using XPS-UPS. Identify degradation mechanism. Investigate reactions of semiconductor/passivation interface.

Year 4- Real-time observation of near-surface changes during bias stressing.

Year 5- Small spot size XPS capability for direct analysis on die

Electrostatic force microscopy - EFM

Scan area in AFM Tapping mode, then apply a bias to the tip and scan in EFM mode.

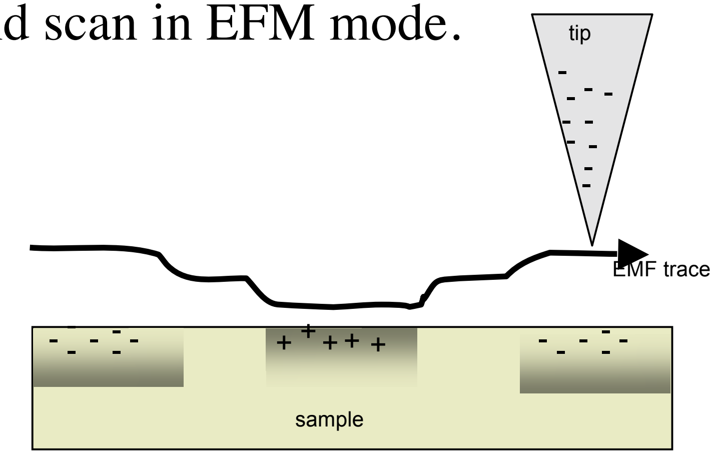
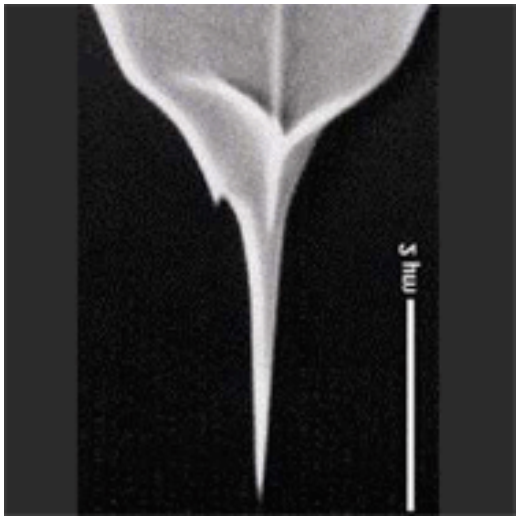


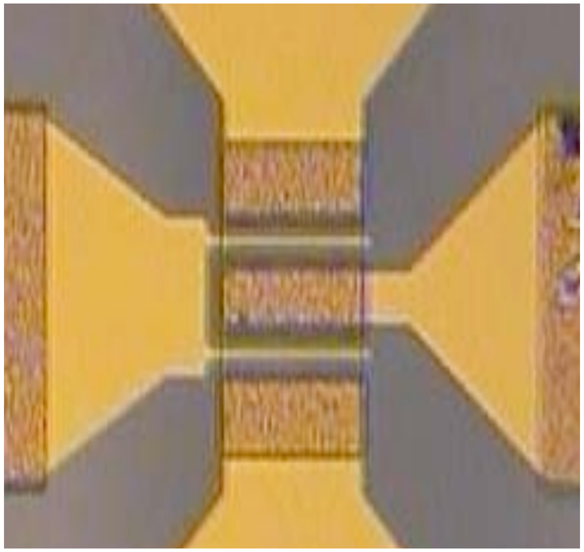
Image of high aspect ratio EFM tip available from Veeco.



Veeco Dimension 3100 with Nanoscope V controller is currently installed in the MAIC facility

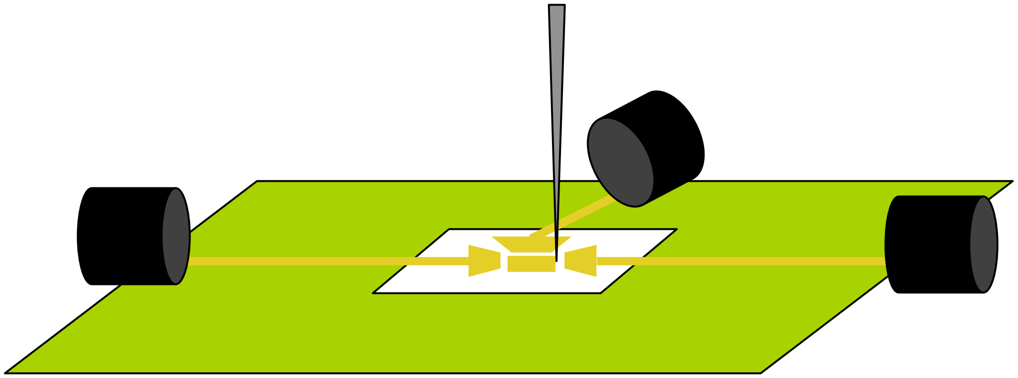
Electrostatic force microscopy - EFM

Applied to pre and post aged devices to scan for variations of the electric field on the device surface.



Examine defects propagating to the surface during testing, electromigration of gate metal in the gate-drain region, and increases in the surface potential from UV illumination emptying traps.

Identify area for TEM/LEAP.



Electrostatic force microscopy - EFM

Projected Milestones

Year 1 – Map the device surface of operational devices varying substrate bias and tip bias. Establish scan parameters for various compound semiconductor surfaces.

Year 2 – Map the device surface of failed devices and establish trends of failure in this region. Design probe cards for device biasing during scanning.

Year 3 – Correlate the failure mode to evolution of defects observed by TEM/LEAP. Incorporate defect generation and field profile into simulators.

Year 4- Real-time imaging of devices during stressing

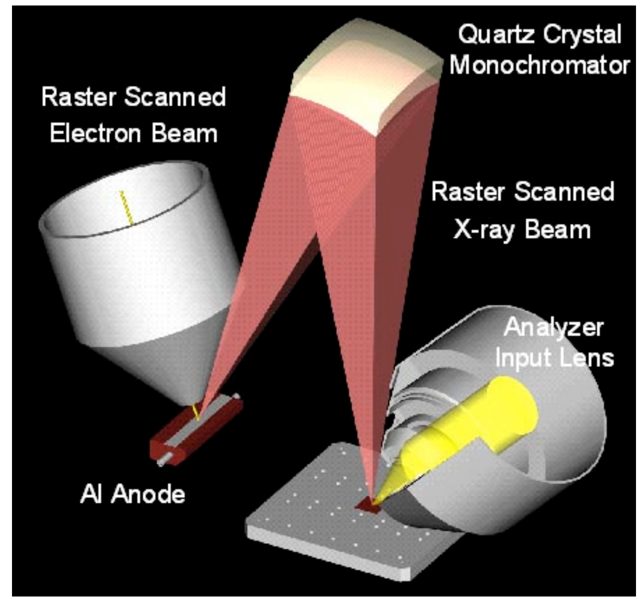
Year 5-Establish limits of predictive forecast of reliability using short bais-aging cycles.

xtra

High resolution XPS/UPS

State of the art tools have <9um spot size and can build chemical maps of the surface – Physical Electronics & Omicron

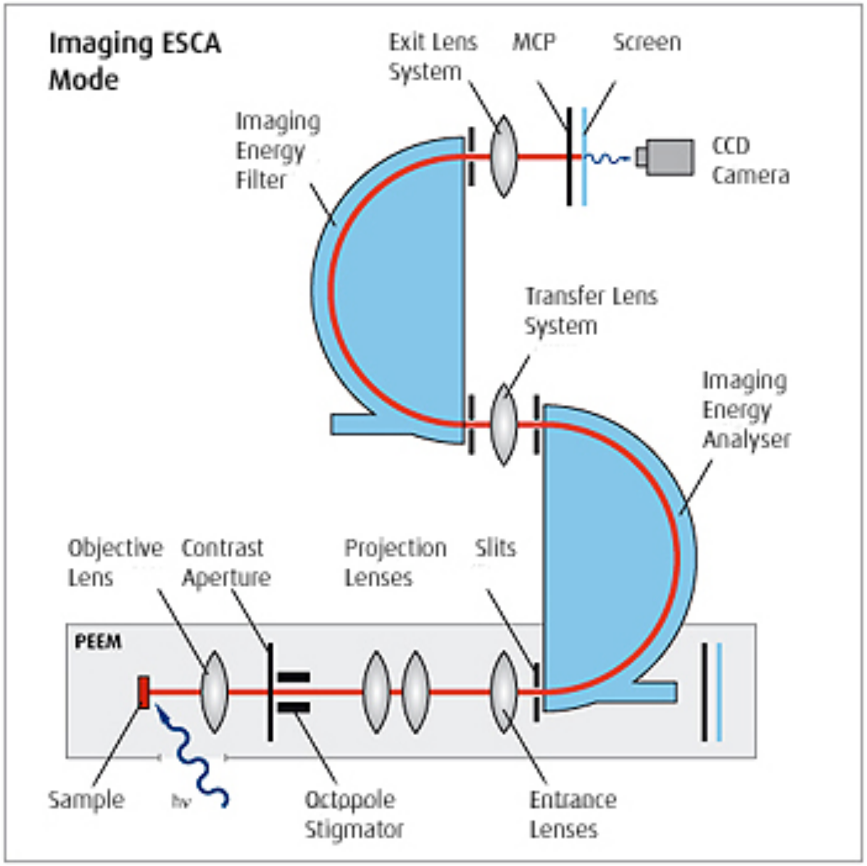
High intensity monochromatic x-ray sources scan the surface.

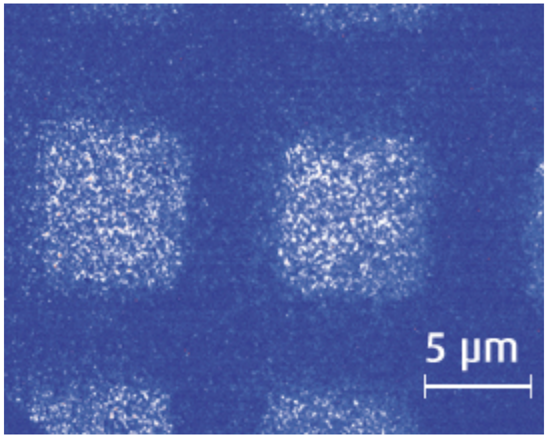



Sphera – 60μm


NanoESCA – 650nm

Imaging Mode XPS/UPS

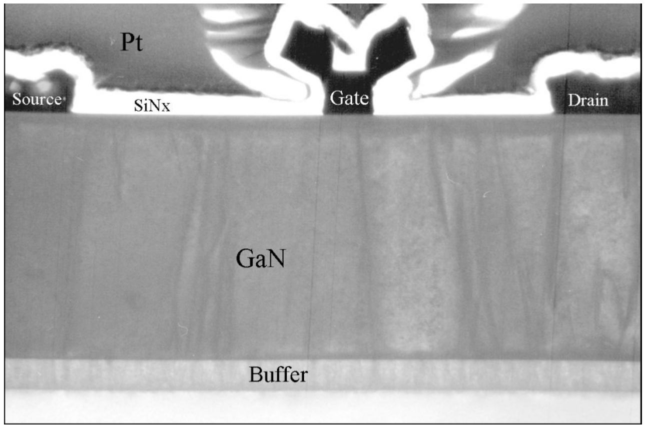


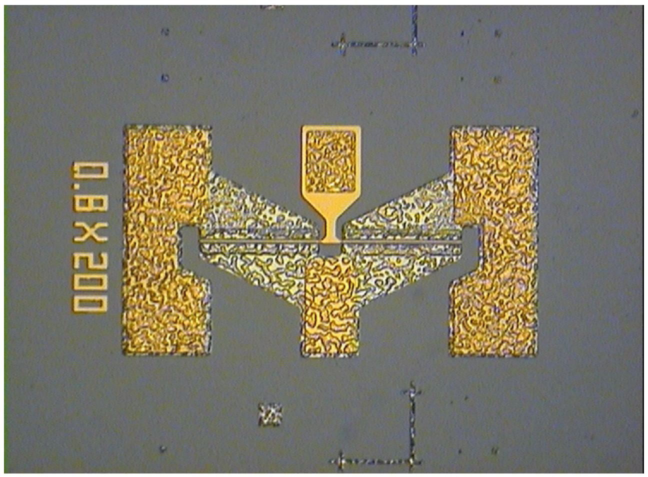


Imaging at high kinetic electron energies. Ag evaporated on Cu, 35 μm field of view, 20 min acquisition time on Ag 3d5/2.

Mode	Resolution	Contrast mechanism	Possible field of view
PEEM	< 50 nm	Survey, topography, work function,...	5 - 500 µm
Imaging XPS (synchrotron)	150 nm	ESCA	5 - 120 µm
Imaging XPS (laboratory)	650 nm	ESCA	5 - 120 µm
Spectroscopy	(200 meV)	XPS, UPS	< 5 µm

Omicron NanoTechnology


Pt
Source
SiNx
Gate
Drain
GaN
Buffer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